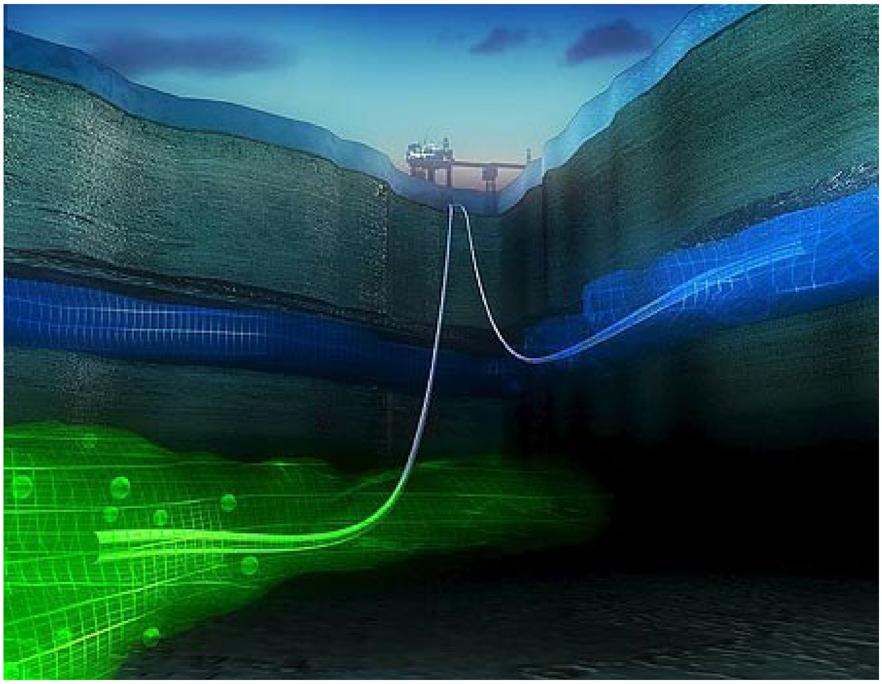
Going underground

Carbon capture and storage may be one way to achieve deep reductions in emissions, but ensuring the gas stays buried will be crucial to proving its viability. **Mark Schrope** reports on a promising new method for monitoring carbon dioxide deep underground.

With coal likely to comprise a sizeable fraction of the world's energy supply for some time to come, the race is on to develop a technology that removes planet-warming greenhouse gas emissions from power-station chimneys and stores them safely underground. Estimates suggest that effective carbon capture and storage (CCS) would strip 80 to 90 per cent of emissions from conventional power plants[1] and could reduce global carbon dioxide emissions one-third by 2050 if deployed on a large scale.

But although its proponents believe that CCS holds huge promise as a clean energy technology, a crucial aspect of proving its viability will be ensuring that the buried gas goes deep underground and stays there. One worry is that carbon dioxide stored in geological repositories could slowly leak out, negating the benefits of burial, or that a storage site close to a populated area could rupture, releasing enough carbon dioxide to suffocate those nearby. Though researchers are confident they can choose sites with geology that renders this virtually impossible, effective, economical monitoring of stored gases will be an essential part of commercial carbon sequestration.

"There are somewhat limited options in the world of geophysics for finding out what's underground," says Mark Zumberge, a geophysicist at the Scripps Institution of Oceanography in La Jolla, California, who is studying carbon burial in the North Sea. But one possibility involves using phenomenally precise measurements of the force of gravity to monitor carbon dioxide in storage sites. Though this method was previously treated with cynicism, new reports[2,3] suggest it may yet prove itself up to the task.



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Artist's rendering of seafloor carbon dioxide storage at StatoilHydro's Sleipner platform.

TRIED AND TESTED

Oil companies have for years been pumping carbon dioxide into oil fields to aid extraction, but the first major test of CCS began in 1996. That year, motivated by a new Norwegian tax of US$50 per ton of carbon dioxide released, Norway's Statoil — now known as StatoilHydro — started stripping carbon dioxide from natural gas flows at its Sleipner platform in the North Sea and pumping it down through 100 metres of water and about a kilometre below the sea floor. There, above the natural gas field where it originated, the carbon dioxide entered a sandy layer that extends for hundreds of kilometres and is capped by an impermeable shale layer that locks in the gas.

As part of the tests at Sleipner, the company wanted to learn how and where the carbon dioxide spread and, crucially, whether it stayed buried. Initially they used the standard method for underground monitoring: a seismic survey, which produces an image of the Earth's subsurface using reflected sound waves. But in time they also grew interested in another possibility. A team led by Zumberge was doing contract work for Statoil using gravity measurements to track the spread of seawater into a natural gas field, and as the work progressed, Statoil began to consider using the same technique to track the spread of buried carbon dioxide. Tore Torp, a StatoilHydro carbon-storage adviser, says that many in the field were sceptical that the gravity measurements would be sensitive enough to monitor the buried gas. But, he says, "These guys just had the courage to do it nevertheless."

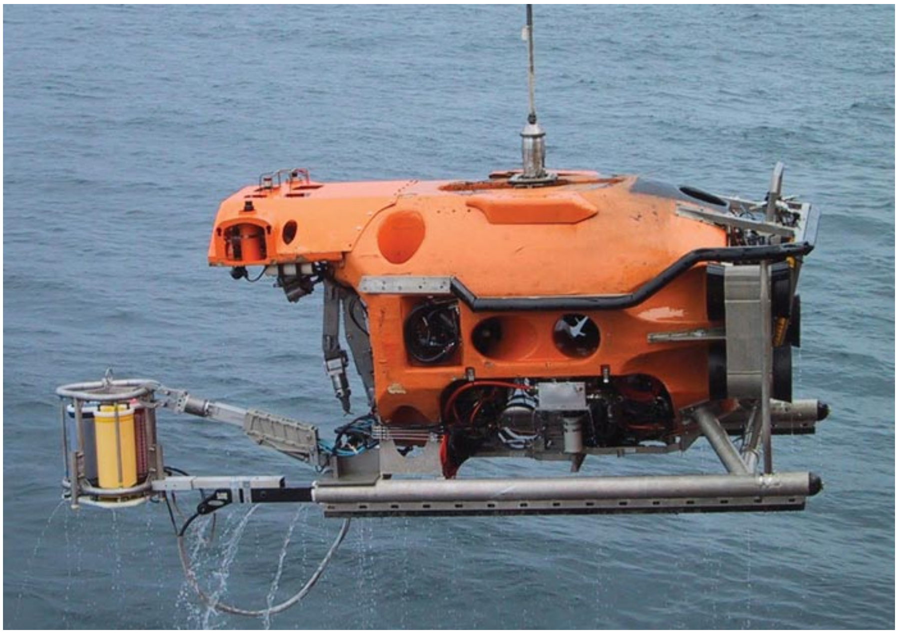
The basic premise of the method is that at any given point on the planet, the density of the material below that point alters the force of gravity ever so slightly. This means the force of gravity is slightly higher at a spot that has seawater below it, compared with one that has less dense carbon dioxide. Decreases in gravity over time at a given spot can reveal the movement of carbon dioxide as it displaces seawater. Unlike seismic surveys, which are effective but have drawbacks such as high costs and potential impacts on marine life, gravity measurements are non-invasive and can in theory reveal density changes with higher resolution. Estimates suggest they could be up to ten times cheaper than seismic surveys.

ENCOURAGING OUTLOOK

During 2003 and 2005, the Scripps group ran gravity surveys of StatoilHydro's North Sea carbon-storage area, where the company has to date pumped some 10 million tonnes of carbon dioxide underground. That's a rate of about 1 million tonnes per year — a substantial volume, but only a fraction of what might be captured from an average power plant. The team's primary tool is a commercially available gravimeter that can measure changes in gravity through the compression or expansion of a spring with a weight attached to the bottom. For their measurements to be useful, the researchers needed to detect changes in the range of a billionth of Earth's gravity. But first they had to get the gravimeters, designed for use on land, underwater. The team took gravimeter measurements at 30 sites around the field. These had to be precisely marked, because gravity measurements are extremely sensitive to location. "We can come back to exactly the same location within a centimetre," says Zumberge.

In an upcoming issue of the journal *Geophysics*, the team reports that they have been able to achieve the remarkable precision needed to effectively monitor the gas underground[2]. Their North Sea results are also in line with seismic data, all of which suggest that the carbon dioxide stored there is spreading as expected and with no signs of leakage. Zumberge cautions, however, that more data are needed to settle the question definitively, and toward that end the team is planning another round of measurements in 2009. "We'll have a longer time series and a bigger volume of carbon dioxide to track," says Zumberge, "but whether or not we will be able to start to talk about leakage is still kind of speculative."

In the same *Geophysics* issue, Erika Gasperikova, at the Lawrence Berkeley National Laboratory in Berkeley, California, and a colleague also report on the basis of smaller-scale tests that gravity measurements should be sufficient in many circumstances for long-term monitoring of carbon dioxide storage sites[3]. However, seismic or other techniques would still be needed, they say — for instance, in the initial detailed characterization of the geology of a potential burial site to ensure it is suitably secure. "I think [the Scripps team] showed that the gravity measurements in real field conditions can give you the information you are looking for," says Gasperikova.



MARK ZUMBERGE

Gravimeters are transported to the sea floor by a remotely operated vehicle.

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The next step toward both proving gravity measurements and significant application of CCS will be larger-scale studies. A number of CCS projects are now underway around the world at locations from France to China, both on land and below the sea, and could involve gravity measurements. StatoilHydro and others are also exploring the possibility of eventually burying much larger volumes of the gas, perhaps captured from power plants planned at onshore locations relatively close to the North Sea burial zone. Ola Eiken, a geophysicist with StatoilHydro, says storage efforts to date have been small compared with the site's potential capacity. "It's just filled a tiny part of the pore space," he says. Theoretically, this same geological feature could hold thousands of millions of tonnes of carbon dioxide — in other words, a huge chunk of Europe's carbon emissions.

Steve Caldwell, a regional policy coordinator with the Pew Center on Global Climate Change in Arlington, Virginia, who is currently preparing a briefing on CCS for the US Congress, says the move towards larger pilot studies can't come soon enough. "We think [CCS] is a promising technology that's likely to play a significant role in providing for emission reductions for the medium to long term," he says, "but the sooner it's ready to go, the better and more cost effectively we'll be able to hit targets."

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